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## ABOUT THE AUTHOR

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## I. INTRODUCTION

International Space Station is a joint venture. Because of this, ISS execution planning- planning within the week for the ISS requires coordination across multiple partner, and the associated processes and tools to allow this coordination to occur. These processes and tools are currently defined and are extensively used.

This paper summarizes these processes, and documents the current data trends associated with these processes and tools, with a focus on the metrics provided from the ISS Planning Product Change Request (PPCR) tool. As NASA's Vision for Space Exploration and general Human spaceflight trends are implemented, the probability of joint venture long duration programs such as ISS, with varying levels of intergovernmental and/or corporate partnership, will increase. Therefore, the results of this PPCR analysis serve as current "Lessons learned" for the ISS and for further similar ventures.

## II. Background

In order to understand how the results of ISS plan process measurement are relevant to any future human space operation, one must review how NASA mission execution planning and replanning evolved from its beginning to how ISS operations are performed today. This historical evolution, and the subsequent ISS planning and replanning process, are discussed in the following subsections.

### *Short Duration Missions for the Moon, and the resultant planning environment*

NASA human spaceflight execution planning has evolved over multiple programs, due to the nature of their missions. A typical Mercury program flight plan was a typed procedural list formatted against a simple mission timeline. As the lunar programs gained in complexity (and as crewmembers were added), the procedural lists in the Gemini and Apollo Mission Flight Plans (including the Apollo-Soyuz Test Program) were replaced by activity blocks that cited the procedures, which in turn, were published in separate procedure books (usually organized by a specific subsystem). Execution replanning during these programs was performed day by day, resulting in significant changes to the plan if required. With these short duration missions lasting 1-2 weeks at most, it was reasonable to expect a realistic Flight Plan developed at the outset of each mission. Most importantly, short duration missions are marked by a need to complete all objectives, as objectives not met during a particular mission faced a high probability of never being completed, if they could not be easily manifested and/or repeated on a subsequent mission. Therefore, mission plans were typically highly optimized prior to launch, and were continually optimized daily over their mission durations. However, this level of replanning intensity would last a few weeks at most.

### *Skylab: the first variation for mission planning*

The limits of short duration plan development and replanning process began to manifest itself with the Skylab program. Since program operations were to support a long duration mission, the ability to develop an execution plan from mission inception to completion (along with the associated schedule detail used during previous programs) was difficult to develop. Furthermore, the Skylab program was the first NASA human spaceflight program to significantly incorporate distributed planning, with the Manned Spacecraft Center (MSC, now known as Johnson Space Center) providing systems support planning and overall plan integration, and the Marshall Spaceflight Center (MSFC) providing payload planning. Thus, the two portions of the plan could not initially be developed together, i.e., in the same room. Finally, scheduled daily plan optimization over a month of execution was inefficient and unnecessary over month-long manned missions onboard Skylab.

The Space Shuttle program saw the return of short duration mission planning as seen in the Apollo program. However, execution planning for the Space Shuttle program evolved - first, with payload planning being performed by MSFC; later, with further distributed planning (via Russia, performed during the Shuttle-Mir program).

### *ISS and the nature of continual execution planning*

The International Space Station (ISS) was always designed as a multinational venture. From the onset of ISS operations, NASA recognized that detailed, scheduled execution planning was not always required for every pre-execution phase. As a result of being multinational, and due to the nature of the vehicle, the ISS program saw both long range plan development and distributed planning. As such, it was recognized that it was desirable for mission execution plans to remain stable over several days and not be replanned day to day as in previous programs. There was no distinct need for day-to-day replanning (unless there was crew risk or a potential for loss of science), since the ISS would remain on orbit for years at a time.

With the ISS, NASA execution planning continued to be shared between two different NASA centers (JSC and MSFC), thus continuing a geographically-dispersed execution planning effort started with Skylab. However, unlike Skylab, the vehicle has been continually staffed onorbit since Expedition 1 arrival, with execution planning broadened to Russia as well. Thus, there has been no “break” from crew, vehicle, and ground plan development and execution since Expedition 1 arrival in November, 2000.

At the publication of this paper, the ISS has not been completely assembled. Further ISS assembly will signal the beginning of European and Japanese execution planning in the process, as well as a continual ISS crew staffing increase from 3 to 6 crewmembers. The current ISS planning/replanning process (enumerated in the following subsections), has been in process since the onset of onorbit ISS operations.

One purpose of this paper is to determine how closely the ISS planning process has adhered to the philosophy of stable daily plans. To do this, we have assessed aspects of the ISS Planning Product Change Request (PPCR) process, which is how execution plans are changed within the ISS Program. However, to do this, we must explain the current ISS planning process, and how the PPCRs fit within this process.

### *ISS planning process initiation*

The ISS planning process is initiated by requirements definition created by the ISS Program Office. These requirements include who, how much, and when the crew will become the ISS crew. This period of time is typically defined as an Increment or Expedition, and is normally a 6 month period defined by when a major portion of the ISS crew is transferred to and from (i.e, rotated) onto and off of the ISS. Each Increment management team then defines the major operational requirements, including all planned vehicle arrivals and departures, as well as all major systems and payloads tasks to be performed during the mission. With the increment requirements set, the various international partner planning organizations develop plans that best satisfy as many requirements as possible.

## Definitions: Planning, scheduling, activities, and procedures

Before examining the ISS planning process in detail, we must define certain terms. In this document, we refer to both planning and scheduling, and procedures and activities. Planning and scheduling are not the same, nor are procedures and activities.

By “planning”, we mean the determination that a particular set of activities can be performed in a particular time frame, performed by comparing their total resource usage against the total resource available for that given timeframe (usually by the day). In contrast, scheduling is defined as the specification of a particular start time and stop time (or duration) for a set of activities to occur. Activities can be scheduled down to the second if necessary, but most activities are normally scheduled within 5 minutes of accuracy.

Plans and schedules consist of activities. An activity refers to a representation of a procedure that is generally executed as a contiguous block of time, either by crew, ground commanding, or both. By contrast, a procedure is an exact callout of the step-by-step process (checklist) required to perform a particular activity.

## ISS Planning Products

### OOS

For ISS operations, the first set of an Increment plan to be developed is an On orbit Operations Summary (OOS). The OOS is typically comprised of activities grouped for each day of Increment operations, and is typically measured against the available crew work day. A work day is defined as 6 hours, 30 minutes for each crew member, Monday through Friday, on a typical work week, exclusive of sleep, meals, planning coordination with ground facilities, and exercise (among other activities).

A preliminary OOS is created and initially negotiated 3 months prior to Increment start, then finalized 1 month prior to Increment start. The OOS is predominantly a listing of activities (mostly crew) on a daily basis. A typical OOS is represented in Figure 1.

**Figure 1: OOS Example**

Week 1		Increment 4 OOS, Final													
		12/10	12	12/11	12	12/12	12	12/13	12	12/14	12	12/15	12	12/16	12
GMT		12/10/01		GMT 344 (MON)		GMT 345 (TUE)		GMT 346 (WED)		GMT 347 (THU)		GMT 348 (FRI)		GMT 349 (SAT)	
DAILY ORBIT		18/9	1	1	1	1	1	1	1	1	1	1	1	1	1
Events		ISS-ADAPTATION[1]		ISS-ADAPTATION[1]		ISS-ADAPTATION[1]		ISS-ADAPTATION[1]		ISS-ADAPTATION[1]		ISS-ADAPTATION[1]		REST[1]	
Metrics	BETA ANGLE	0		0		0		0		0		0		0	
	ISS CDR	HMS-PMC[1] N33-MO-7[1] N33-MO-8[1]		HMS-PMC[1] PAO-EVENT[1] PAO-PREP[1] UF-1-COR-UNPACK[1] N33-MO-107[1] TKT7-IMS CDR-XFER[3]		CONF-COR-IMS[1] HMS-PMC[1] PAO-EDU-EVENT[1] PAO-PREP[1] UF-1-COR-UNPACK[1] N33-MO-5-COR[1] TKT7-IMS CDR-XFER[2]		PAO-EVENT[1] PAO-PREP[1] UF-1-COR-UNPACK[1] N33-MO-5-COR[1] TKT7-IMS CDR-XFER[2]		FD/ISS CREW-CONF[1] WEEKLY PLAN-CONF[1] TKT7-IMS CDR-XFER[2]		CONF-COR-IMS[1] HMS-PMC[1] CFO-CLN[1] CFO-ACY-B-EX-RAR[1]		CONF-COR-IMS[1] HMS-PMC[1] CFO-CLN[1] CFO-INSPECT[1]	
	FE-1	HMS-PMC[1] RENAL-FE1-INGESTION[1] N33-MO-7[1] N33-MO-8[1]		EHS-CSA-CP ALC-DPLY[1] HMS-PMC[1] PAO-EVENT[1] PAO-PREP[1] RENAL-FE1-INGESTION[1] SAPS-ACTIVATION[1] SSC-FS-REFRESH[1] UF-1-FE1-UNPACK[1] N33-MO-107[1]		BSTC-EXP-DAY-2[1] BSTC-FAM[1] EHS-CSA-CP ALC-DOWNLD[1] PAO-EVENT[1] PAO-PREP[1] RENAL-FE1-INGESTION[1] UF-1-FE1-UNPACK[1]		BSTC-EXP-DAY-2[1] BSTC-FAM[1] EHS-CSA-CP ALC-DOWNLD[1] PAO-EVENT[1] PAO-PREP[1] RENAL-FE1-INGESTION[1] UF-1-FE1-UNPACK[1]		BSTC-EXP-DAY-3[1] BSTC-FAM[1] FD/ISS CREW-CONF[1] RENAL-FE1-INGESTION[1] WEEKLY PLAN-CONF[1]		RENAL-FE1-INGESTION[1] CFO-CLN[1]		RENAL-FE1-INGESTION[1]	
	FE-2	HMS-PMC[1] RENAL-FE2-INGESTION[1] N33-MO-7[1] N33-MO-8[1]		TKT7-IMS FE1-XFER[1] CMS-HRM 5/4-PRP[1] HMS-PMC[1] PAO-EVENT[1] RENAL-FE2-INGESTION[1] SSC-FS-REFRESH[1] UF-1-FE2-UNPACK[1] N33-MO-107[1]		HMS-PMC[1] PAO-EDU-EVENT[1] PAO-PREP[1] RENAL-FE2-INGESTION[1] UF-1-FE2-UNPACK[2] TKT7-IMS FE2-XFER[3]		PAO-EVENT[1] RENAL-FE2-INGESTION[1] UF-1-FE2-UNPACK[1] N33-MO-5-COR[1] TKT7-IMS FE2-XFER[1]		CMS-HRM DATA-ERASE[1] FD/ISS CREW-CONF[1] RENAL-FE2-INGESTION[1] WEEKLY PLAN-CONF[1] TKT7-IMS FE2-XFER[2]		RENAL-FE2-INGESTION[1] CFO-CLN[1]		RENAL-FE2-INGESTION[1]	
	Any crew	UF1-PL-STATUS [1] COX-MNT[1]		TKT7-IMS FE2-XFER[1] ER2-ELC-PARUP[1] HMS-DEFIB-C/O[1] PAO-SETUP[1] UF1-PL-STATUS [1] COX-MNT[1]		CMS-IVIS WEEKLY-MNT[1] IMS-FILE-PREP[1] PAO-SETUP[1] UF1-PL-STATUS [1] COX-MNT[1]		BSTC-EXP-DAY-2[1] IMS-FILE-PREP[1] PAO-SETUP[1] UF1-PL-STATUS [1] COX-MNT[1]		BSTC-EXP-DAY-3[1] CMS-EXER FILE-DOWNLD[1] CMS-HRM FILE-DOWNLD[1] CMS-MEC DATA-D/L[1] IMS-FILE-PREP[1] UF1-PL-STATUS [1] COX-MNT[1]		UF1-PL-STATUS [1] COX-MNT[1]		UF1-PL-STATUS [1] COX-MNT[1]	
Metrics	Crew CDR	0.66		4.91		5.08		5.33		2.91		3.75		0.41	
	Crew FE-1	0.67		5.5		5		6.09		5.92		2.25		0.25	
Crew	Crew FE-2	1.08		5.75		5.92		3.34		3.25		2.25		0.25	
	Crew *	1.08		2.25		2.08		2.35		2.66		1.08		1.08	
TOTAL Crew		3.43		18.43		18.1		17.1		15.76		9.35		2.01	
Dock Ports								6 PROG/SM AFT 3 SZ/FGN NADIR							
ATTITUDE								LVLH							

The WLP is developed two weeks prior to execution, and becomes the basis for actual schedule development. A Weekly Lookahead Plan typically consists of two sets of products: a plan of all activities for a given week (Monday through Sunday), and a preliminary “best efforts” schedule to accommodate those activities, based on the planners’ understanding of the relationships between the activities and the requested communications coverage for ISS. See Figures 2 and 3 for WLP examples. All activities added or subtracted from the WLP must be documented with a PPCR.

[illegible]

**ISS-3 WLP #7 (01 Oct-07 Oct) Final**

**Day 1: 10/02/01**

ISS CDR: SLEEP (01-08), POSTSLP (08-09), MEAL (12-13), MEAL (14-15), MEAL (16-17), PRESLEEP (22-23), SLEEP (23-24).  
 ISS PLT: SLEEP (01-08), POSTSLP (08-09), MEAL (12-13), MEAL (14-15), MEAL (16-17), PRESLEEP (22-23), SLEEP (23-24).  
 FE-1: SLEEP (01-08), POSTSLP (08-09), MEAL (12-13), MEAL (14-15), MEAL (16-17), PRESLEEP (22-23), SLEEP (23-24).  
 SYS: SLEEP (01-08), POSTSLP (08-09), MEAL (12-13), MEAL (14-15), MEAL (16-17), PRESLEEP (22-23), SLEEP (23-24).  
 Activities: 01-08 SLEEP, 08-09 POSTSLP, 09-10 MEAL, 10-11 MEAL, 11-12 MEAL, 12-13 MEAL, 13-14 MEAL, 14-15 MEAL, 15-16 MEAL, 16-17 MEAL, 17-18 MEAL, 18-19 MEAL, 19-20 MEAL, 20-21 MEAL, 21-22 MEAL, 22-23 PRESLEEP, 23-24 SLEEP.

**Day 2: 10/03/01**

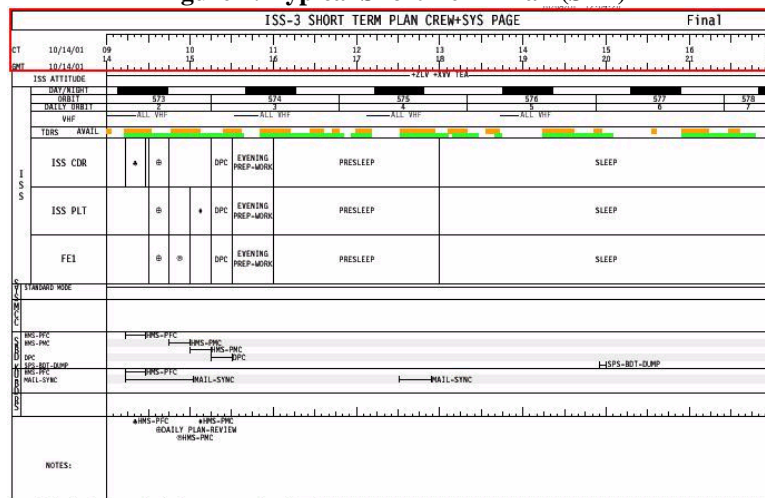
ISS CDR: SLEEP (01-08), POSTSLP (08-09), MEAL (12-13), MEAL (14-15), MEAL (16-17), PRESLEEP (22-23), SLEEP (23-24).  
 ISS PLT: SLEEP (01-08), POSTSLP (08-09), MEAL (12-13), MEAL (14-15), MEAL (16-17), PRESLEEP (22-23), SLEEP (23-24).  
 FE-1: SLEEP (01-08), POSTSLP (08-09), MEAL (12-13), MEAL (14-15), MEAL (16-17), PRESLEEP (22-23), SLEEP (23-24).  
 SYS: SLEEP (01-08), POSTSLP (08-09), MEAL (12-13), MEAL (14-15), MEAL (16-17), PRESLEEP (22-23), SLEEP (23-24).  
 Activities: 01-08 SLEEP, 08-09 POSTSLP, 09-10 MEAL, 10-11 MEAL, 11-12 MEAL, 12-13 MEAL, 13-14 MEAL, 14-15 MEAL, 15-16 MEAL, 16-17 MEAL, 17-18 MEAL, 18-19 MEAL, 19-20 MEAL, 20-21 MEAL, 21-22 MEAL, 22-23 PRESLEEP, 23-24 SLEEP.

### Short Term Plan (STP)

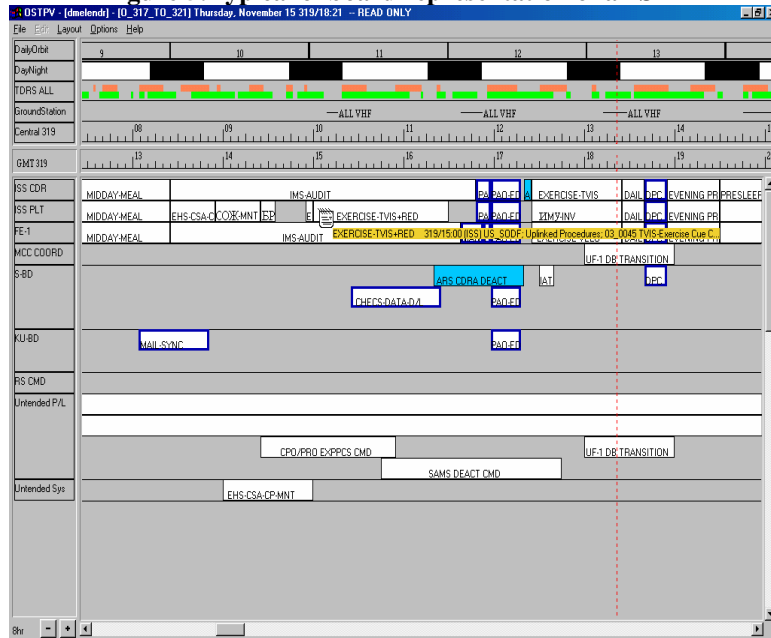
The STP is a daily schedule of activities initially developed 7 days prior to execution, and finalized 6 days prior to execution. The STP is developed Long Range Planners (LRPs), and reviewed by Flight Control Team. Each day, each Flight Control Team shift must review the Short Term Plan 7 days in the future. The STP consists of scheduled activities developed during the WLP process, as well as any activities added or subtracted by PPCRs that have been approved by all relevant control centers, as well as schedule changes based on confirmed communications coverage for that day. With the finalization of the STP, any further changes to schedule or other ancillary activity information (Execution Notes) must be documented and agreed to by all relevant control centers via PPCR.

In parallel with the final STP plan integration, the Moscow Control Center produces two plan products: the Form 24, and the ДППП. The Form 24 is a redundant crew activity plan matching the STP, and the ДППП is a redundant set of key ground activities associated with both the Form 24 and the STP. MCC-Moscow requires plan stability 3 days prior to execution in order to develop the Form 24 and ДППП. Therefore, all Control Centers perform a final review of all activities, searching for any potential PPCRs to be written, so as to assure that the redundant plans are consistent with each other. As a result, ISS Flight Rules establish that any plan changes beyond this 3 day period must meet Critical Replanning Criteria (CRC) and be coordinated directly between voice communication between the Houston and Moscow Control Centers.

**Figure 4: Typical Short Term Plan (STP)**



**Figure 5: Typical onboard representation of an STP**

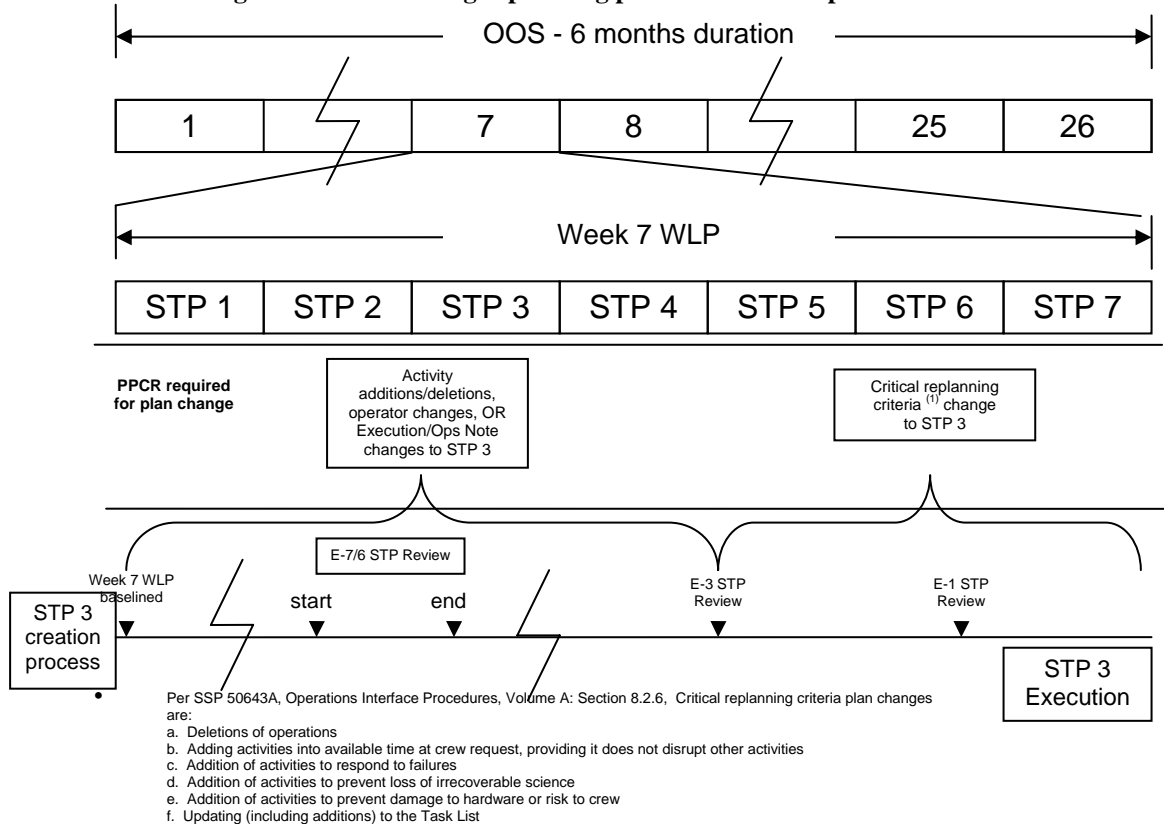


### *PPCRs and the replanning timeline*

As was stated earlier, in order to ensure plan conformance with newer information, PPCRs are required to be written at appropriate times. The replanning process, and when PPCRs are required, is illustrated in Figure 6.



**Figure 6: ISS Planning/replanning process relationship to PPCRs**



As stated earlier, different forms of PPCRs are required when known representations of the execution plan must change. Figure 7 shows a summary listing of PPCRs.

**Figure 7: Typical PPCR status page**

PPCR #	Title	Discipline	Status	MCM	MCM	POIC	SSIPC	COLCC
15-0513	Add FE-2 PFC For GMT 160	SURGEON	Open	A	D	A	IO	IO
15-0512	P/TV-BPSMU-S/U Execution Note Modification	PTV	Implemented	A	IO	IO	IO	IO
15-0511	RS changes to 10-Jun (GMT_161)	OPSPLAN	Open	IR	IR	IR	IO	IO
15-0510	Execute Note for GMT 159 EMU-RELOCATE	EVA	Implemented	A	IO	IO	IO	IO
15-0509A	EPS Activities	PHALCON	Implemented	A	IO	IO	IO	IO
15-0508	MCC-H/M CMD and TLM Ground Connection/Disconnection For RS EVA 19	GC	Implemented	A	A	IO	IO	IO
15-0507	GMT 157 Update Exec Notes for Ping Test	CIO	Implemented	A	IO	IO	IO	IO
15-0506	Add A/L10A2 Panel Removal to Task List starting 06-June (GMT 157)	ECLSS	Implemented	A	IO	IO	IO	IO
15-0505	Update FE-2 PFC Time on GMT 160	SURGEON	Open	A	D	A	IO	IO
15-0504	RS changes to GMT 157	OPSPLAN	Implemented	A	A	IO	IO	IO
15-0503	Add Message Reference to EVA-TOOL-CONFIG	CIO	Implemented	A	IO	IO	IO	IO
15-0502	US updates to GMT 158	OPSPLAN	Implemented	A	IO	IO	IO	IO
15-0501	Add A/L CCAA activities on GMT 158	ECLSS	Implemented	A	IO	IO	IO	IO
15-0500	RS changes to ALTCRISS on GMT 159	OPSPLAN	Implemented	A	A	A	IO	IO

In the PPCR status page above, each PPCR is represented in each row. A PPCR may contain one or many plan change requests, which can be for one or more days. Each PPCR is monitored by the Operations



Planner and is recommended for review/approval based on its content, as is indicated by the columns on the right hand side of Figure 5. As the PPCRs are approved, each status indicator is turned from a yellow “IR” (in review”) indicator to a green “A” (Approved) indicator. The white “IO” indicators stand for “Information Only” – the control center in question is not affected by the plan change contained in the PPCR. (Note that in the example above, the PPCRs are numbered starting with a “13-”: this means that they were created during Expedition 13, which had no ESA or JAXA modules or operations and as such, all PPCRs were marked “Info Only” for their associated control centers (COLCC and SSIPC)).

The contents of a typical PPCR is illustrated in Figure 8.

**Figure 8: A typical PPCR**

The screenshot shows a web browser window titled "PPCR OPS1 - MCC-Houston - Windows Internet Explorer". The address bar shows "https://ops1.jsc.nasa.gov/default.asp?iss". The page has a header with various navigation tabs including ADCC, PHALCON, THOR, OSO, ODIN, ECLSS, Ops Plan, CIO, ACO, ROBO, CATO, HSG, POD, MER, ATV R/O, ATV PD, CAPCOM, TOPO, TITAN, ATLAS, EVA, VVO, Surg/BME, GC, Pointing, PAQ, MSG, SPAN, IMC, COL PD, J-FLIGHT, and J-FLIGHT. Below the header is a table with columns for Actions, Anomalies, Chvls, EFN, Host/Mat, IMGO, IMAS Search, IPV, JEDI, OSTPV, PPCR, PDI, and Tool Cmnts. The main content area shows a form for a PPCR with the following fields: Title (Update to execute notes for Tasklist item and GMT162 Slip Plan), Source(s) (BME), Constraints (This is an update to execute notes for the TVIS MONTH-MNT tasklist item. Please note that this activity is also hard time-lined for the GMT162 slip plan. Please update these execute notes accordingly.), Rationale (Update to execute notes.), and a table for line items. The line item table has columns for Date(s), From, To, and a description of the change. The status is "Open" and the submitter is "SURGEON/SGROVER".

Each line item within a PPCR may contain one or more additions, deletions, or modifications to an activities’ start time (either within a day or movement from one day to the next), procedure reference, duration, time criticality (an indicator that an activity must be performed at a particular time). PPCRs may also contain activity deletions. In addition, a PPCR contains when each line item was created and by whom (discipline and individual name). The PPCR itself is also associated with a unique number, revision (if any), submitting discipline and submitter discipline and name, submission date and time, descriptive title, PPCR source, description of PPCR activity constraints, and rationale for the PPCR (as submitted by the submitter).

### *Why analyze the PPCR database?*

If the created plans and associated information were “perfect”, there would be no need for PPCRs. However, things happen to prevent the plans from being “perfect”. PPCRs are generated due lack of insight into the procedure for the activity when the plan is developed, changing TDRS communications coverage understanding (either through TDRS network scheduling conflicts with other users, or changes in ISS trajectory or attitude configuration causing changes in confirmed communications coverage), real time events conspiring against the plan (hardware and software failures, science opportunities revealed), crew input, or any combination of these reasons and others not listed here.

Analyzing the PPCR database can provide trends that may be consistently changing the plan. Furthermore, understanding when the PPCRs occur can allow the ISS mission planners to potentially “front load” the planning process with the necessary data and characteristics to prevent plan changes later, which may allow for the possibility of reducing real time replanning (and associated replanning cost) later in the planning process.

Thus, the point of this paper is to summarize PPCR analysis which was performed to determine if there are:

1. Systemic on orbit problems that keep manifesting themselves as PPCRs
2. Ground issues in the planning process which force PPCR creation (which may cause reevaluation of the milestones in the replanning process)
3. Trends indicating if a particular discipline or activity type requires more PPCRs over time (implying that some resources might be needed to keep that type of trend from hitting the FCR all the time, and that plan changes are being made closer and closer to Realtime)

By analyzing the PPCR data base, specific analysis questions that can be assessed. These assessments include:

1. When are PPCRs typically issued? Do PPCR submittals correlate to a day of the week, and what could this imply for weekly staffing and PPCR decision making?
2. How often do the Flight Control teams meet the deadline for PPCR submittal at 3 days prior to execution, and what is the overall PPCR submittal timing trend?
3. Are there any types of events that meet it (or not) more often than others?
4. Do certain disciplines that seem to require more PPCRs than others?
5. How many line items are typically submitted in each PPCR? This assessment and the PPCR timing assessment, indicates how busy the real time replanning team becomes in coordinating the plan as it moves toward execution.

### *PPCR Assessment*

In order to performin this assessment, it is clear that all PPCRs being assessed must be assessed against the same process. While the schedule for ISS stage operations PPCR writing has been clear since first ISS launch, the criteria for PPCR writing has not. Because of this confusion, on 21 July 2004, Operations Planners met to establish which types of activity or plan changes did not require PPCR documentation. The result was subsequently documented in the Flight Control Operations Handbook in October 2005. Because this establishment did not occur until late July 2004, the author restricted the PPCR database analysis to PPCRs written from August 2004 onward. It was also realized that the replanning process during joint Shuttle missions (due to the factors described earlier in this paper) are different than those employed during “stage” (i.e., non –joint-Shuttle) periods. Therefore, any subsequent PPCR analysis was limited to PPCRs not written during joint Shuttle operations from August 2004 onwards.

### *Analysis Inputs*

Two reports were initially generated from the PPCR database of the PPCRs written from January 2003 through April 2007. One report consisted of a summary of each PPCR written; the second report consisted of the details of each PPCR. Together, these reports initially included over 14000 PPCRs, representing over 45000 plan changes.

By definition, PPCR details page report was much larger than PPCR summary page, as PPCR details page report consisted of data for each line item with a proposed plan change (add, delete, or modify), whereas the PPCR summary page was just that – a summary of the PPCR in total.

The relative sizes of each report are tabulated in Table 1.

**Table 1: Breakdown of PPCRs assessed from August '04 to April '07**

	<b>Report 1(1 line per PPCR)</b>	<b>% of pretotal</b>	<b>Report 2(1 line for each PPCR line entry)</b>	<b>% of pretotal</b>
Report1 + Report2 (Pretotal)	<b>14005</b>	<b>100%</b>	<b>45920</b>	<b>100%</b>
LESS:Pre-August '04 PPCRs (early)	<b>4182</b>	<b>30%</b>	<b>13773</b>	<b>30%</b>
	<b>9823</b>	<b>70%</b>	<b>32143</b>	<b>70%</b>
LESS:Items in Report 2 not in Report 1	<b>0</b>	<b>0%</b>	<b>19</b>	<b>0%</b>
	<b>9823</b>	<b>70%</b>	<b>32124</b>	<b>70%</b>
LESS:Joint Mission PPCRs	<b>437</b>	<b>3%</b>	<b>4049</b>	<b>9%</b>
	<b>9386</b>	<b>67%</b>	<b>28075</b>	<b>61%</b>
LESS:Withdrawn PPCRs	<b>675</b>	<b>5%</b>	<b>5051</b>	<b>11%</b>
<b>TOTAL PPCRs/line items assessed</b>	<b>8711</b>	<b>62%</b>	<b>23024</b>	<b>50%</b>

### *PPCR Categorization*

In order to properly assess the PPCR database, each PPCR needed to be categorized, and this PPCR categorization needed to be assessed against appropriate criteria. Current ISS operational documentation stipulates what plan changes are necessary (SSP 50643A, Operations Interface Procedures, Volume A: NASA/Rosaviakosmos (June 2003)). These critical replanning criteria, for 3 days prior to execution, as defined in section 8.2.6 (Replanning During Steady State Operations) are:

- Deletions of operations
- Adding activities into available time at crew request, providing it does not disrupt other activities
- Addition of activities to respond to failures
- Addition of activities to prevent loss of irrecoverable science
- Addition of activities to prevent damage to hardware or risk to crew
- Updating (including additions) to the Task List

In categorizing the PPCRs, the author roughly categorized each PPCR based on the critical replanning criteria above.

**1= Task List entry/update** – these are activities that are added to the plan but are not scheduled. They may be optionally executed only as the crew desires. **This corresponds to Critical replanning criteria f**

**2= Deletion only** – these are PPCRs that only deleted activities off of the plan. **This corresponds to Critical replanning criteria a.**

**3= Addition at crew request** – self explanatory. **This corresponds to Critical replanning criteria b.**

**4= Response to failure or preventing loss of critical science** – these are activities that were added or modified into the plan so as to allow repair to some portion of the ISS and/or to keep critical scientific payloads or payload support equipment from failing. **This corresponds to Critical replanning criteria c and d.**

**5= Preventing damage to hardware or risk to crew** – these are PPCRs adding or modifying the plan so as to prevent hardware/software damage or crew risk. **This corresponds to Critical replanning criteria e.**

In addition to these five criteria, it was determined that there were seven other sets of criteria by which plan changes were required. These were categorized as follows:

**6 = Facility only - no impact to non-MCC-H** – these are PPCRs documenting facility activities that were required to be on the plan for MCC-H cognizance, but had no impact on any interface between MCC-H and other control centers or between the other control centers and the ISS. As such, they were marked “Info Only” for all other control centers.

**7 = Facility only - impact to non-MCC-H** – these are PPCRs similar to category 6, but which did affect the MCC-H or ISS interface. These were not marked “Info only” for the other appropriate control centers

**8 = Update to Execution or Operations Notes** – these PPCRs were typically written to provide reference between the activity and the procedure necessary to perform the activity. These PPCRs were needed whenever a procedure had been recently finalized and verified relative to its execution on orbit.

**9 = Multiples of other types** – PPCRs which were a combination of any other type of PPCR (including the TBD category)

**10 = Changes due to updates in communications coverage or trajectory** – PPCRs which documented plan change as a result in updates in communications coverage or trajectory

**11 = Attitude Timeline (ATL) update-** Attitude control experts in Houston and Moscow maintain a separate attitude timeline which is normally reflected in the WLP and initial STP. This set of PPCRs documents the changes which occurred to the ATL after the initial STP agreement

**12= Volumetric constraint** – these are PPCRs created to avoid spatial conflicts between two or more crewmembers. Typically, these were created to avoid conflict between treadmill exercise activities and activities requiring access near the volume in which the crewmember performing the treadmill exercise required.

**TBD** = PPCRs whose creations did not fall into any other category

### *Methodology*

To obtain the answers to the questions posed earlier in this report, the author manipulated the two PPCR database reports developed by Mission Operations support personnel, sorting either the PPCR database summary, PPCR line item report, or both, to obtain the answers.

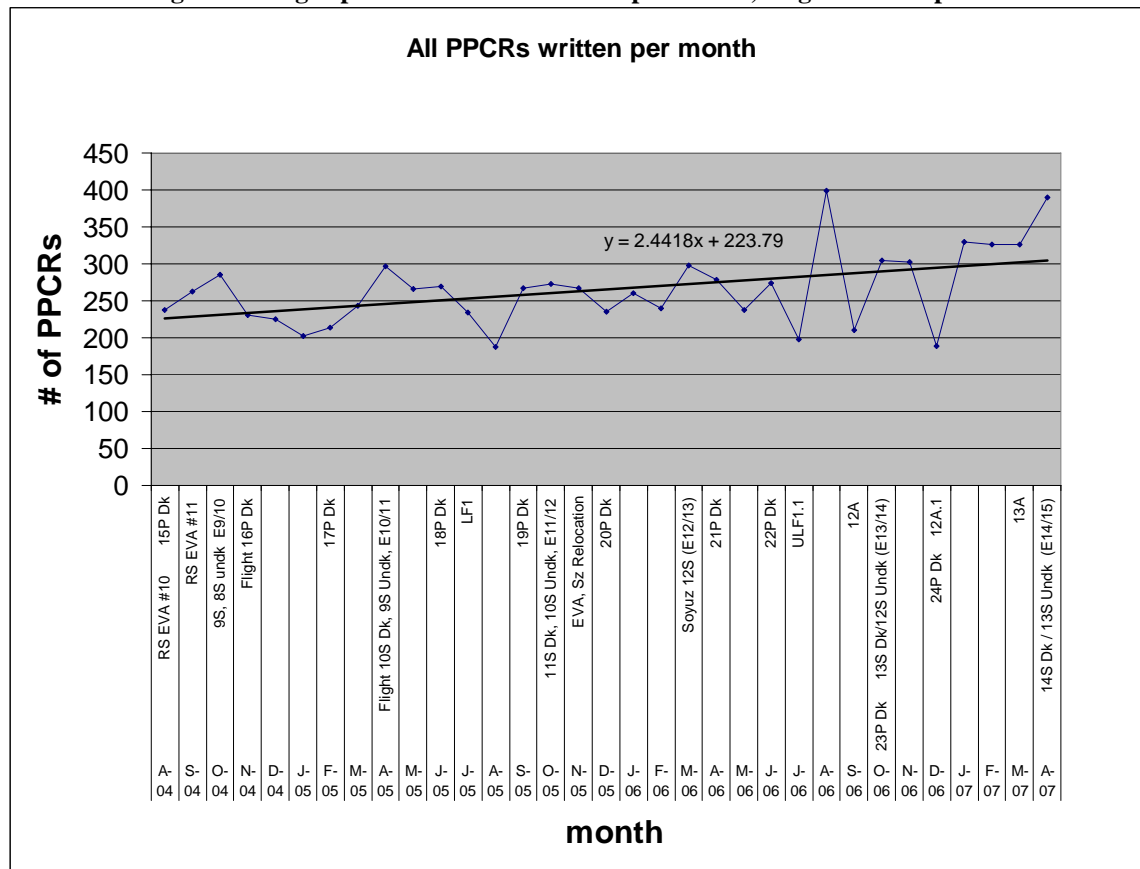
Manipulate the database this way ...	To determine:
Sort PPCRs based on what day of the week PPCRs are written on	Which days of the week we get the most PPCRs, and possibilities for console staffing
Calculate # of PPCRs and # of PPCR line items	Avg # of line items per PPCR (summarized by month). This implies the work load for the Ops Plan team for that month
Sort PPCRs by initiation date/time and date of first plan change, with associated delta between the two	How many PPCRs violate E-3 cutoff How many PPCRs are implemented by LRP vs. Ops Plan How many PPCRs are implemented post-execution
Sum up PPCRs by month	Histogram of PPCRs over time
Classify each PPCR by category	What types of PPCRs constitute the most PPCR traffic (which determines what types of replanning problems to work on - or can be worked on)

### III. Results

#### *Stage PPCRs by the month - Total PPCRs, and high frequency category PPCRs*

Figure 9 illustrates the relationship, month to month, between the total number of PPCRs written in any given month (less joint mission and withdrawn PPCRs) over time. the author also performed a linear least-squares fit equation (via Microsoft Excel operations) to this data.

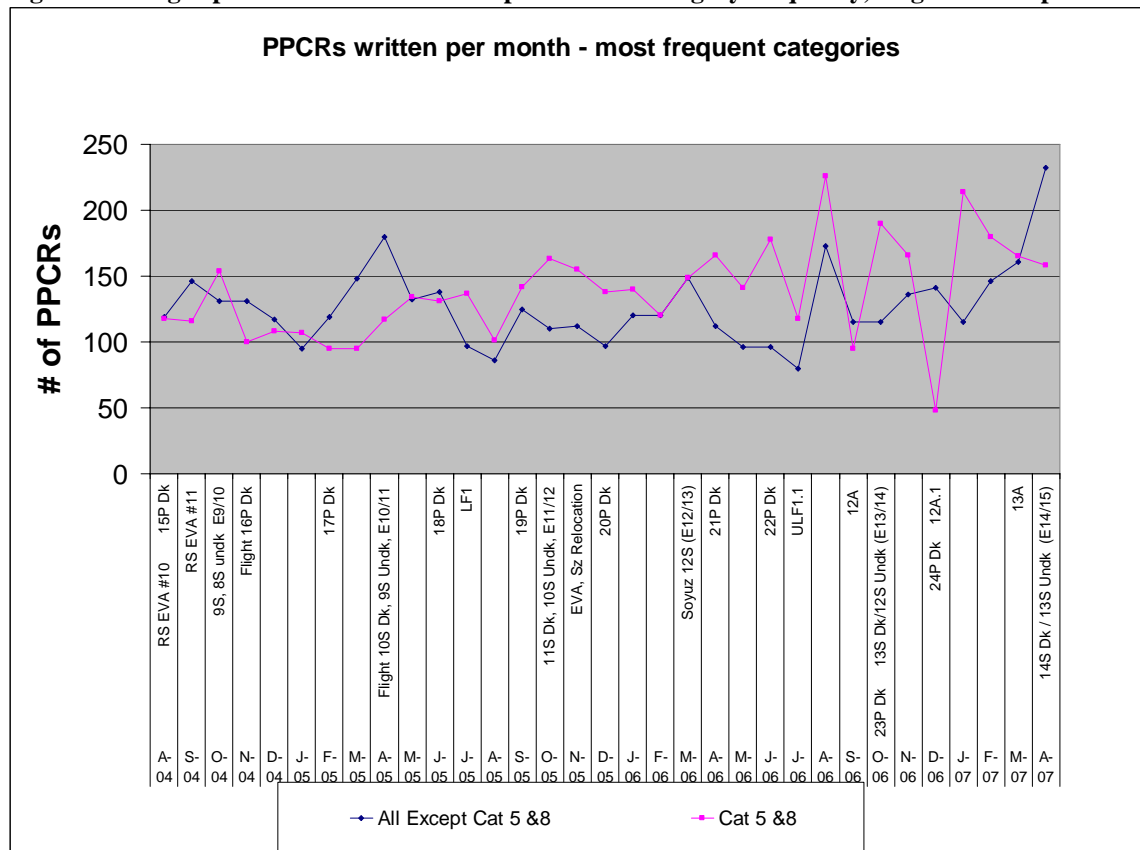
Figure 9: Stage operations PPCRs written per month, August '04 - April '07



What is important about the above chart is not the total number of PPCRs written in any given month, or where the y-intercept of the equation is (233.8). What is most important is the **slope** of the line. As can be seen from the equation and the general shape of the data, the operations team is writing approximately 2.5 more PPCRs each month (note that by excluding joint mission data, the actual amount of PPCRs written is actually greater than what is shown here).

A further examination of the data shows that PPCRs written under categories 5 (Preventing damage to hardware or risk to crew) and 8 (Update to Execution or Operations Notes) were the most frequent sources for PPCR writing. Figure 10 below shows the breakdown of how the PPCRs were written over time. As can be seen from the graph, categories 5 and 8 together accounted for almost as much as all other categories combined.

**Figure 10: Stage operations PPCRs written per month - category frequency, August '04 - April '07**



### PPCR timing assessment

As was shown in Figure 9, slightly more PPCRs were written month to month from August '04 to April '07. However, from a workload or safety standpoint, what is not known from Figure 9 is how close the PPCRs are being written relative to when their respective activities need to be executed. The closer the PPCRs come to execution, the more severe the implication for replanning.

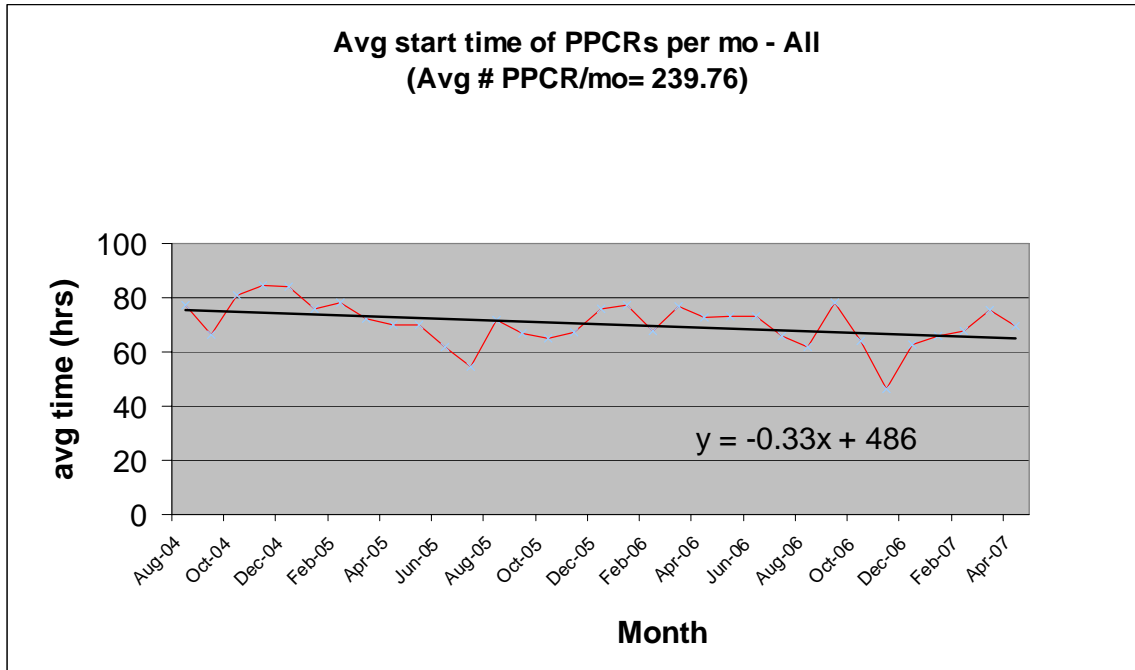
In determining this factor, the author calculated the “delta start time”, which was defined as the earliest activity affected by each PPCR, relative to when the PPCR was initiated. There was a great range of delta start times across the PPCRs, including negative delta start times (which was possible since PPCRs are sometimes written to document plan changes agreed to between control centers after the activity being changed is scheduled in the plan). Because of this range, the delta start times were averaged for each month across the PPCR period being assessed. The relationship of the average monthly delta start times for all PPCRs is illustrated in Figure 11, along with a linear least-squares curve fit.

In June 2006, the ISS increased its crewmembers from 2 to 3. To determine what effects the additional crewmember might have had on PPCR writing, the author calculated the average number of PPCRs for each category and the least-squares curve fit for each category during the 3 crew period only. Table 2 is a summary of the average number of PPCRs per month and slope of the linear least-squares curve fit for each category, for both the entire period and for the 3 crew period.

Again, as with Figure 9, the key to the figure above is not the actual absolute numbers; rather, the essential parameter is the **slope** of the least-squares curve fit. In this case, the slope of that curve is negative, indicating that the average delta start time, month to month, is coming closer to the actual execution time –

in this case, by approximately 20 minutes each month. This is a negative trend which must be monitored and controlled by ISS execution management.

**Figure 11: Average start time of PPCRs written per month (all categories), August '04 - April '07**





**Table 2: Average number of PPCRs per month and average rate**

Category (sorted by Average # of PPCRs per month for 3 crew timeframe)	August '04 - April '07		3 crew only (June '06 - April '07)	
	Average # of PPCRs per month	Rate of delta time change, month to month (hours)	Average # of PPCRs per month	Rate of delta time change, month to month (hours)
5-Preventing damage to hardware or risk to crew	75.03	-0.80	84	-0.77
8 - Update to Execution or Operations Notes	62.82	0.27	71.1	0.34
TBD	27.24	-0.54	24.7	1.49
4- Response to failure or loss of critical science	20.24	0.03	22.1	1.15
9 - Multiples of other types	12.55	0.32	17.7	6.03
2 - Deletion only	12.03	-0.34	14.5	1.18
6 - Ground only - no impact to non-MCC-H	7.97	-2.98	10.9	2.81
7 - Ground only - impact to non-MCC-H	7.81	-3.55	10.3	-3.27
1- Task List entries	11.56	-0.21	8.5	-4.67
10 - Changes due to updates in comm/ballistics	13.06	-0.14	8	1.73
3- Addition at crew request	7.13	-0.03	7.56	5.91
12 - Volumetric constraint	1.75	-0.12	2	88.12
11 - ATL update	1.84	0.45	1.83	7.39
All	258.12	-0.33	279.2	0.59

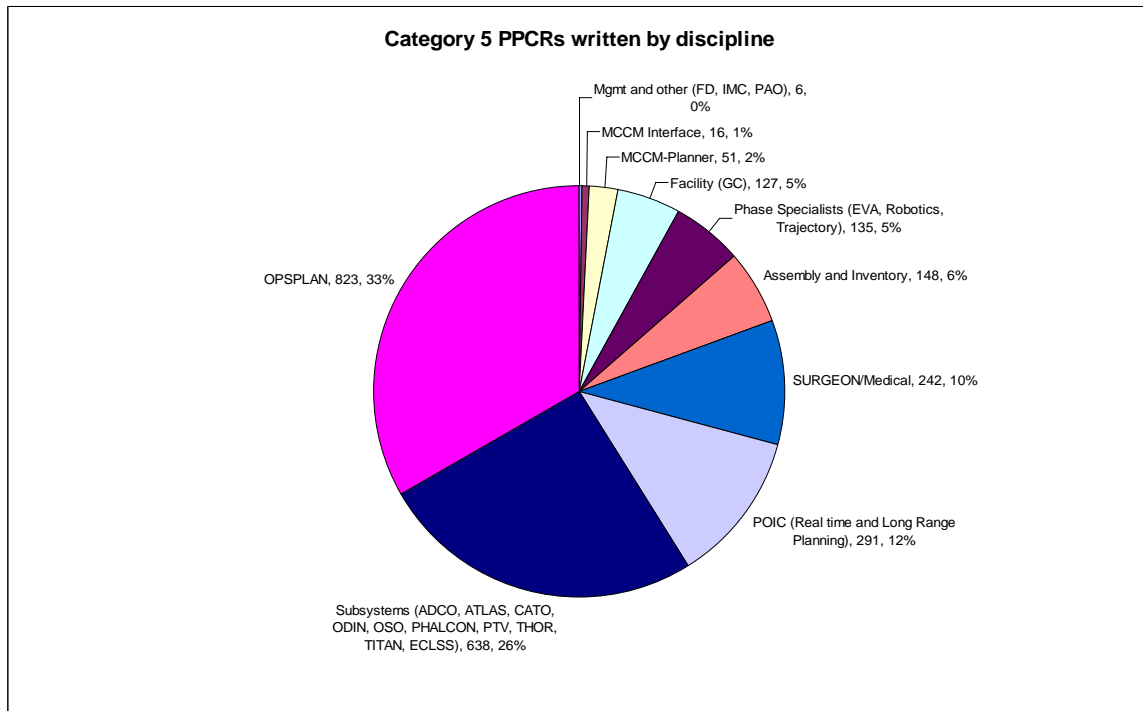
#### Category 5 and 8 PPCR contributions

From examination of Table 2 and Figures 9 and 10, it is clear that the “Preventing damage to hardware/risk to crew” and “Update to Execution or Operations Notes” categories are the highest frequency PPCRs written, based on the average amount of PPCRs written under those categories - regardless of how many crewmembers were onboard.

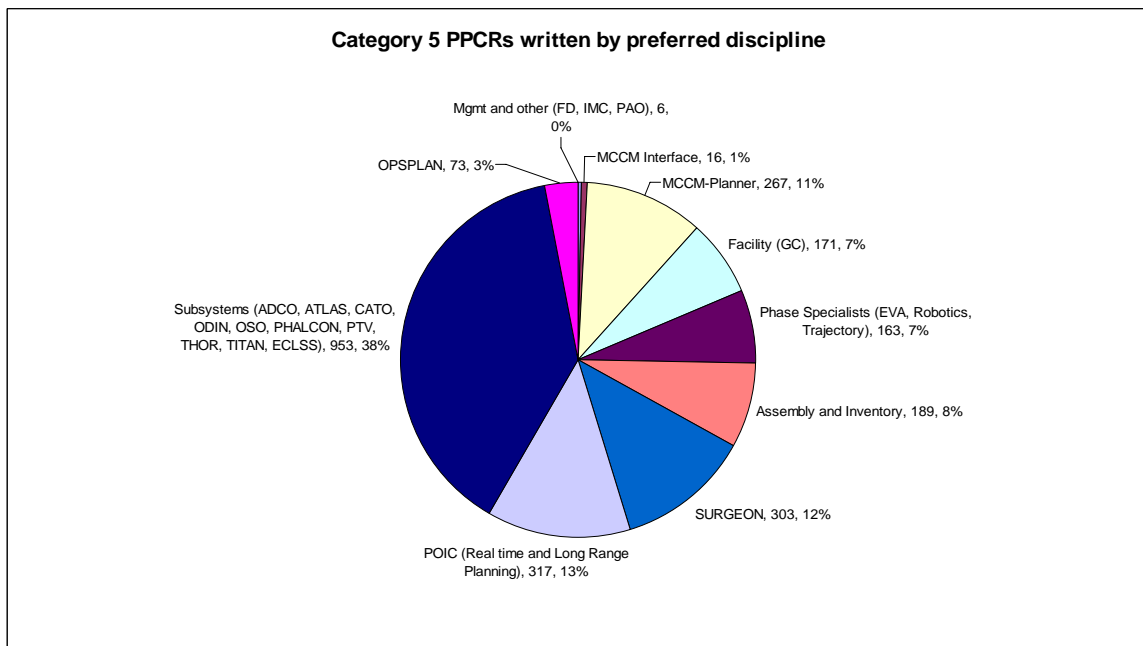
It is also noted that the timing of when PPCRs which update Execution or Operations Notes are written is fairly stable.

Category 5 PPCRs (Preventing damage to hardware/risk to crew) is pretty important. At first glance, it looks as if the is Long Range Planner (LRP) or OpsPlan is responsible for approximately 1/3rd of all Category 5 PPCRs written (See Figure 12). But when the PPCRs are reassessed (based on the subject matter foreach PPCR), it looks like Ops Plan is writing PPCRs for multiple organizations (see Figure 13). This reflects the fact that the Long Range Planners are replanning much of the WLP, with discipline and management coordination, prior (and sometimes, during) STP development. In addition, Russian-based PPCRs are usually written by replan requests in Russian, and these replan requests are translated to English and placed in the PPCR tool by OpsPlan personnel. As a result, much of the PPCR traffic by the LRP and OpsPlan team is on behalf of Russia and other disciplines. This PPCR traffic should be written by other disciplines. However, any transition from Ops Plan to these other disciplines would require specific steps, none of which are assured to be implemented (see Conclusion).

**Figure 12: Initial sources of Category 5 PPCRs, per discipline, August '04 - April '07**



**Figure 13: Adjusted sources of Category 5 PPCRs, per discipline, August '04 - April '07**



#### *PPCR assessment versus plan review milestones*

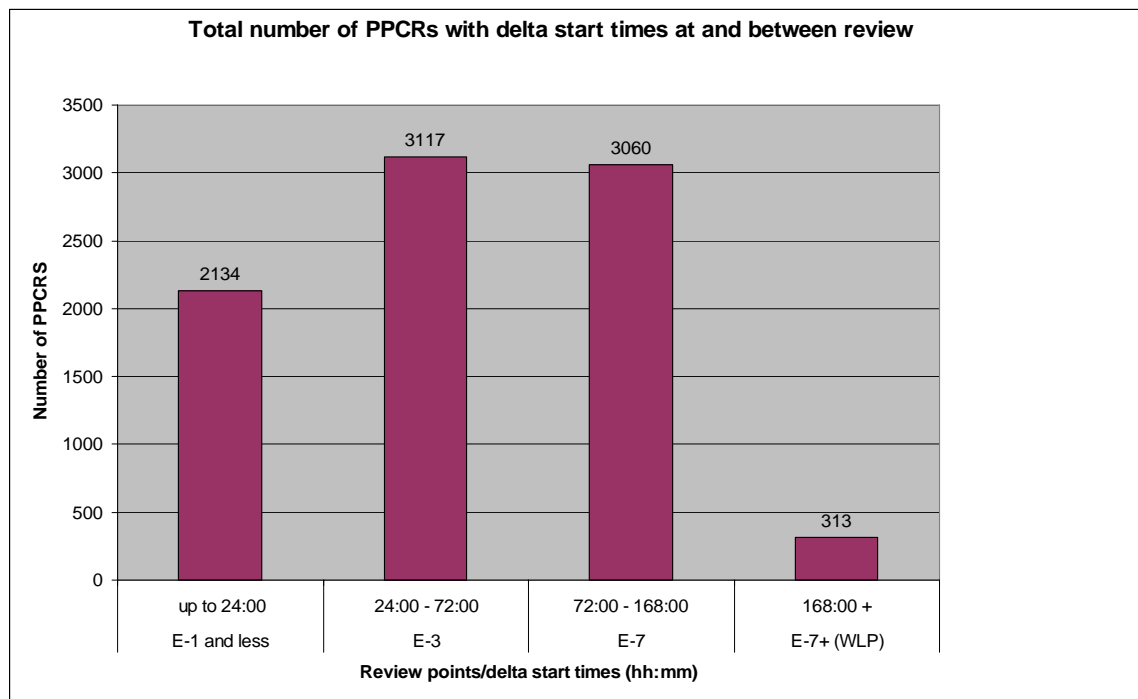
In assessing the PPCRs, it is also desired to review how effective the various plan reviews are.

As was illustrated in Figure 6, each STP undergoes three plan reviews: an E-7 plan review (seven to six days prior to execution), an E-3 plan review (to determine if any additional plan changes must be made - via PPCR), and as a safety check, an E-1 plan review. These plan reviews are also driven by the intent to synchronize STP/OSTP development with Russian Form 24 and ДПП.

As was stated earlier, one intent of the planning process is to not continually replan the next day's plan. This approach, while more acceptable for shorter duration missions such as the early lunar missions and Shuttle, significantly drives cost and is not acceptable for longer-term missions such as the ISS. Furthermore, a vast daily replan and the associated coordination between the various operational organizations (such as MCC-M, POIC, and eventually others), over time (weeks and months), increases the probability of reference plan information errors going onboard.

To assess the effectivity of each plan review, the author sorted the delta start time of each PPCR based on four ranges of duration. The totals of each of these ranges are illustrated in Figure 14.

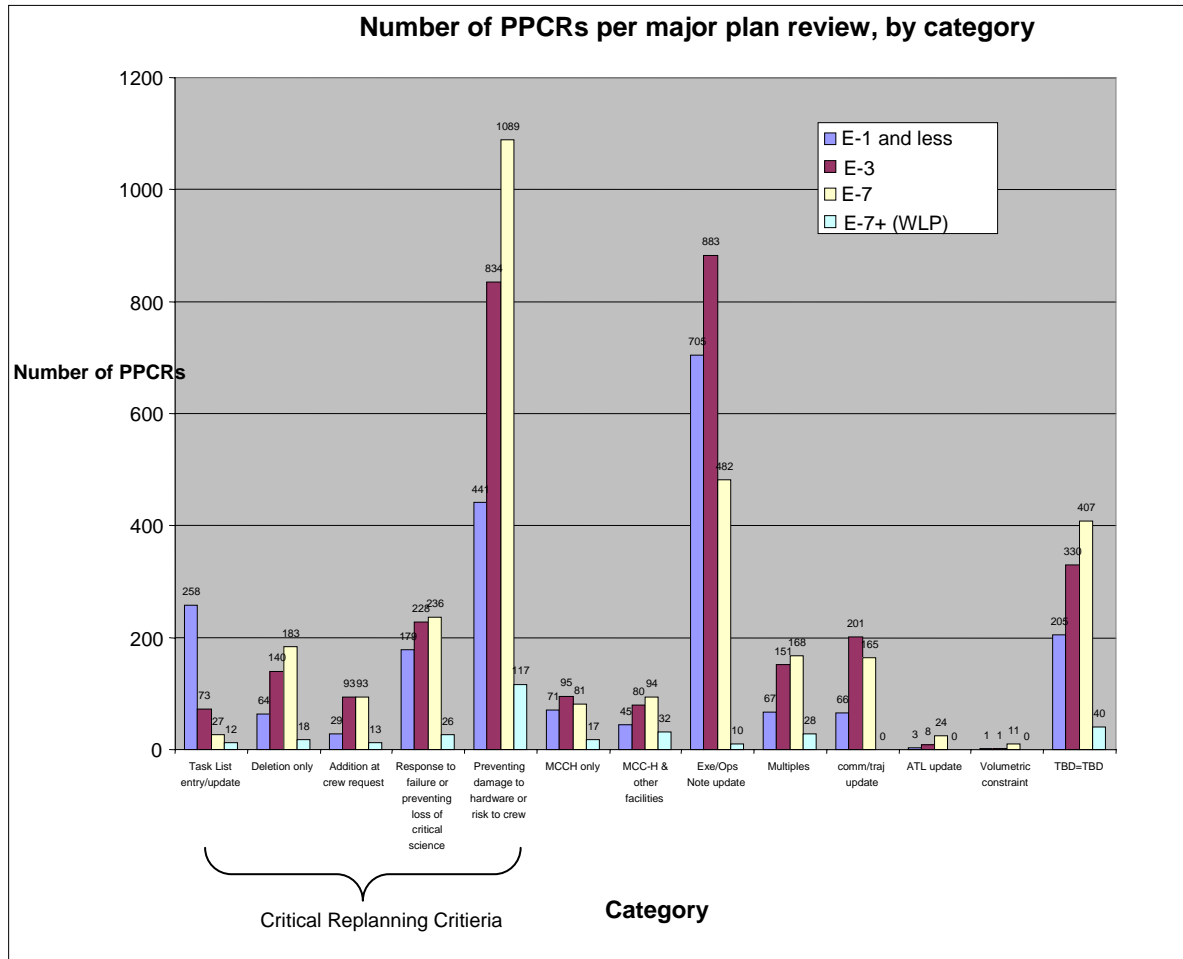
**Figure 14: Total PPCRs based on delta start times at major STP reviews, August '04 - April '07**



As can be seen from the above figure, very few PPCRs are written prior to the first plan review, as expected. However, an almost equal number of PPCRs are written at E-3 and E-7 timeframes. In addition, a significant number of PPCRs are written after E-3, which technically must be written based on the critical replanning criteria illustrated in Figure 6.

Further breakdown of the PPCRs in each of these time ranges, by category, is illustrated in Figure 15.

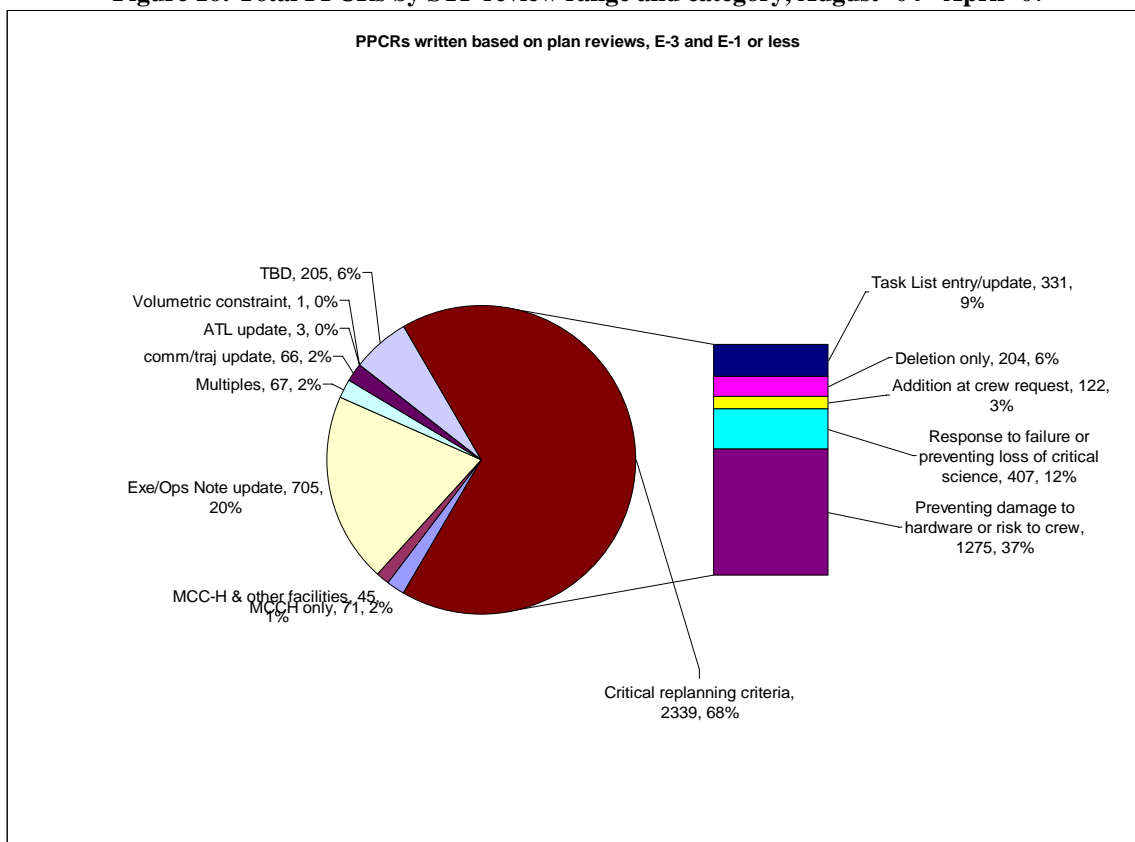
**Figure 15: Total PPCRs by STP review range and category, August '04 - April '07**



Consistent with other analysis results, categories 5 (Preventing damage to hardware or risk to crew) and 8 (Execute and Ops Note update) are the highest categories for almost all plan review ranges - including the critical “E-1 and less” review range.

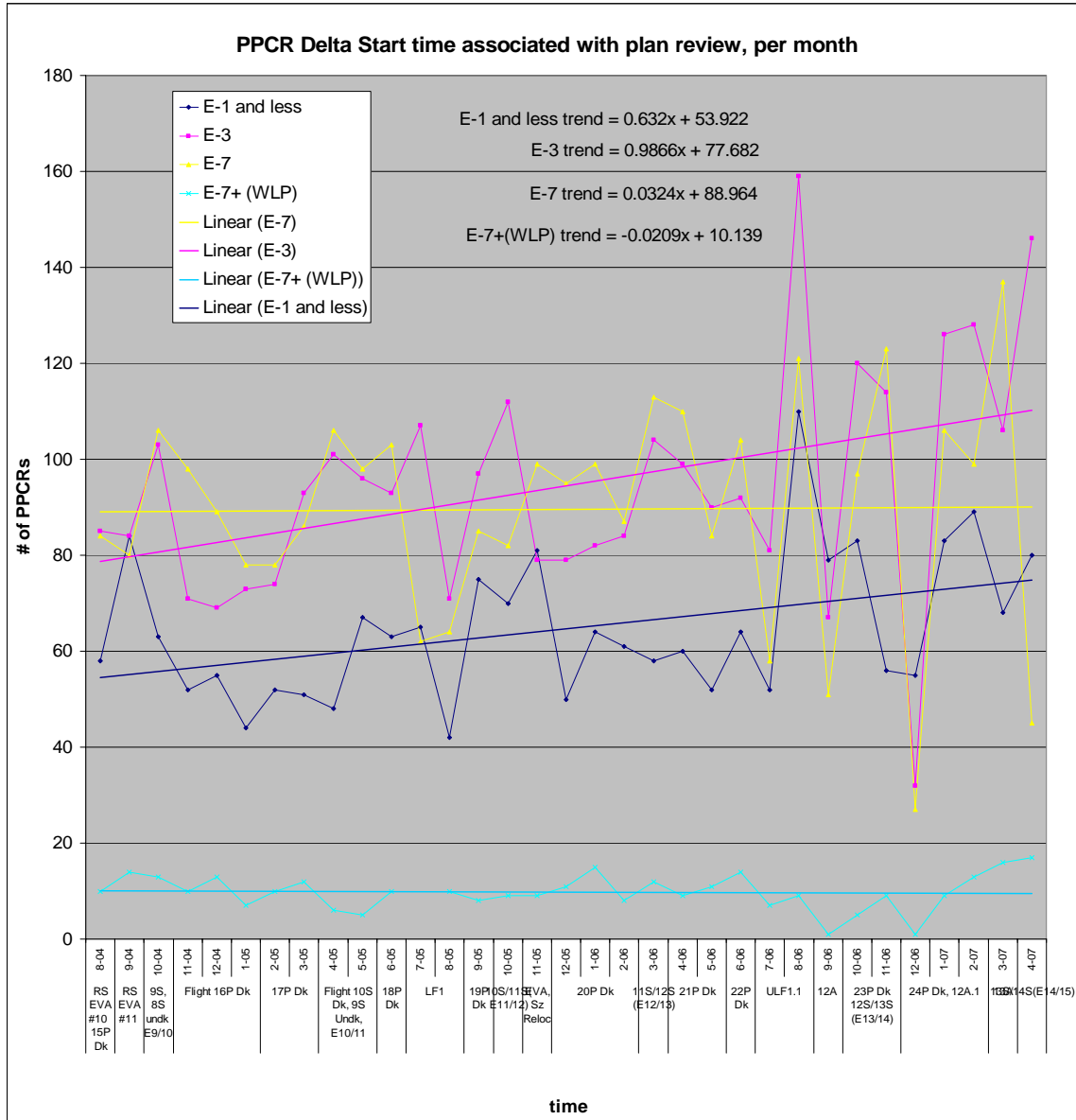
The actual amount of PPCRs written against the critical replanning criteria for those plan review phases that require plan changes to only be written against critical replanning criteria is illustrated in Figure 16. Although there are obvious overlaps between categories, Figure 16 shows that a large percentage (approximately 1/3rd) of the PPCR traffic seen after the E-3 cutoff cannot be determined to be easily measured against critical replanning criteria.

**Figure 16: Total PPCRs by STP review range and category, August '04 - April '07**



The tabulation of the total amount of all PPCRs for each of these review ranges, month to month, is illustrated in Figure 17.

**Figure 17: Total PPCRs received based on STP review cycle, August '04 - April '07**



Note that, as with Figure 9, the key parameter is the **slope** of each linear least-squares curve fit. As can be seen from the figure the trend for later reviews is unfortunately producing more PPCRs as time progresses, and that WLP baselining PPCRs are either flat or decreasing.

#### IV. Discussion

While compiling the lengthy data necessary to develop the charts for this report, it became clear to the author that there was a significant discrepancy in the quality of the PPCRs written. While most PPCRs had significant justification for modifying the plan, many others had poorly-written rationale from which PPCR categorization had to be determined.

## V. Conclusions

Several conclusions can be made from PPCR compilation, trend analysis, awareness of future ISS operations, and awareness of potential further human space operations. The major conclusions are listed in the paragraphs below.

**1. Implement strategies to decrease PPCR writing and/or accelerate their receipt earlier in the STP review process.** The STP and OSTP represent not only the integration between systems and payloads planning and between international partners, but also the confluence of several discipline-specific subplanning processes inherent in the plan content, which the Operations Planners must somehow integrate into a cohesive product for Flight Control team(s) and crew execution. These subprocesses include:

- ATL updates and the DPP versus OSTP planning/replanning
- Facility maintenance planning versus the nominal ISS planning process
- Procedure development and verification processes (the source of Category 8 PPCR inputs)

versus the nominal ISS planning process

Therefore, in order to reduce execution planning change, ISS execution management must assess the fit of each of these planning subprocesses into the integrated execution plan represented in the STP.

**2. Increase measurement accuracy by increasing PPCR quality.** In measuring the PPCRs, it was clear that a percentage of PPCRs are poorly written such that it is difficult to understand why the PPCR is written after the fact. This problem will be exacerbated with additional International Partner (ESA, JAXA) participation.

To circumvent this problem, NASA operations representatives should:

- Increase scrutiny of PPCR rationale writing so that PPCR categorization can be more accurate
- Clarify for the team as to how and when a PPCR should be written
- Decrease % of PPCRs that need to be rewritten by the OpsPlan team

This last possible tactic will be challenging, since:

- MCC-M has developed a dependency of using Replan Requests vice inputting plan changes into the PPCR tool, and has not (except in rare instances) implemented English as the operations language for ISS

- Systems disciplines are less cognizant of overall plan change, thus are less aware when the plan must change (greater than a few days into the future or at/near focused events for the discipline, such as EVAs or Robotic activities)

**3. ISS challenges to come, and what to measure.** This range of PPCR analysis did not include packet swapping operations. In addition, plans are in place for ESA (COL-CC) and JAXA (SSIPC) participation in Execution planning – but these International Partners have not yet participated in execution planning/replanning and as such, are not yet included in this PPCR analysis. Finally, plans are being developed for the ISS crew to be increased to 6 crewmembers over the next two years. Because none of these operational considerations was being performed during the PPCR analysis range, their affects on replanning and associated PPCR writing have yet to be assessed, although it is reasonable to assume that their affects will cause PPCR writing and plan change to increase.

As Figure 9 showed, almost 2.5 PPCRs are being written over time. However, the key parameter is not just how many more PPCRs are being written per month, but how much *plan change by line item* and *how recent the plan change of each PPCR line item become* (Figure 11).

Given the upward trends in PPCR writing month to month and the trend showing a decrease between PPCR submittal to first activity execution in the PPCR, ISS execution management should keep assessing ISS stage operations PPCRs for further trend analyses (probably quarterly). They should watch:

- When the PPCRs are created (particularly with respect to the official plan reviews), what the average number of PPCRs written per month is, and the change in the average number between months (linear slope) as a rolling trend over 3 months
  - Could assess rolling averages historically as well, for year to year comparisons



- - Perform similar analyses for key PPCR categories
- What week day the PPCRs come in over the quarter
- Which IP/center is writing the PPCRs, and why

**4. Perform other assessments.** In performing and documenting this effort, the author was not able to consider assessing the following relevant PPCR analysis questions for ISS:

Manipulate the database this way ...	To determine:
Calculate # of PPCRs and # of PPCR line items	Avg # of line items per PPCR. This implies the work load for the Ops Plan team
Sort PPCRs by non "Info Only" status	What % of PPCRs are reviewed by which centers
Sort PPCRs by initiation date/time and date of first plan change, with associated delta between the two	How many PPCRs violate E-3 cutoff How many PPCRs are implemented by LRP vs. Ops Plan How many PPCRs are implemented post-execution
Sort PPCRs by initiating discipline	Which disciplines supply the most PPCRs
Sort PPCRs by initiation time	Histogram of PPCRs by hour/shift in an average day
Classify each PPCR line item: "Editorial", "Main change", "driven by main change"	How many PPCRs/PPCR line items are editorial

**5. Observation for subsequent space operations.** Any organization wishing to emulate distributed, continuously-operated human tended space vehicles or operations should consider watching the ISS planning and replanning processes.

## VI. Summary

To further elaborate on the last recommendation, in the July 2007 edition of *Aerospace America*, NASA's Associate Administrator Shana Dale was quoted as saying that the Global Exploration Strategy for for Lunar development "... saw contributions from over 1,000 people and 14 space agencies ...", as well as all 10 NASA centers. While the author of this paper was and is not a contributor to this effort, it is reasonable to assume that more than one NASA center and more than one space agency will perform integrated operations - including execution planning - on the Moon. Therefore, the experiences and lessons learned from execution planning on ISS will serve as the lessons learned for such an endeavor.

## Acknowledgments

I would be remiss if I did not acknowledge the following persons in their support of this documentation effort:

United Space Alliance employees Jason Hadlock for developing the PPCR reports, and Wanessa Mattos and Dorothy Ruiz, for their help in PPCR classification  
 NASA-Johnson Space Center ISS Operations Planning Group Leads Scott Curtis and Jennifer Price, and Flight Director David Korth, for reviewing this paper.  
 My wife and family, for putting up with this effort.